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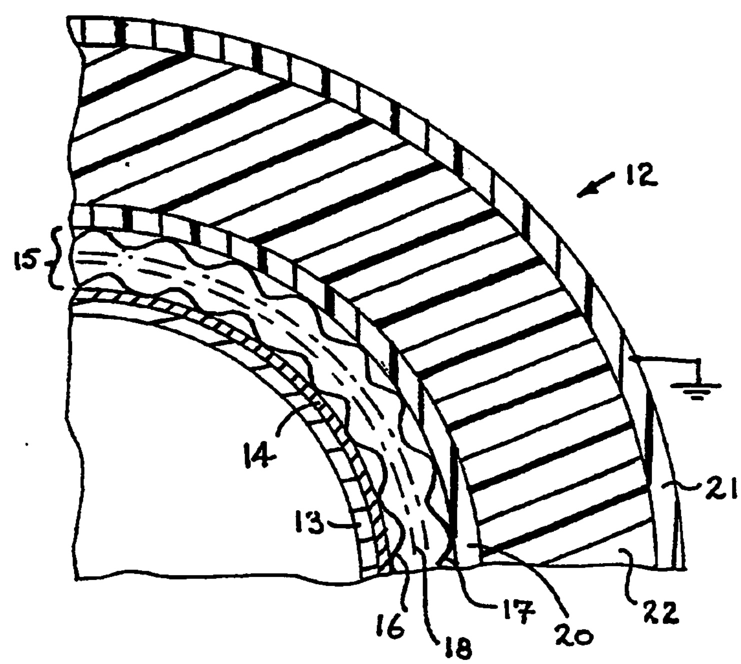
(54) Title: A POWER TRANSFORMER

(57) Abstract

A power transformer (1) having at least one electrical winding comprising electrical conducting means (13-15), cooling means for cooling the electrical conducting means to improve its electrical conductivity, and surrounding electrically insulating means (20-22) comprises an inner layer (20) of semiconducting material in electrical contact with said electrical conducting means, an outer layer (21) of semiconducting material at a controlled electrical potential along its length and an intermediate layer (22) of electrically insulating material between the said inner and outer layers (20, 21).



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A Power Transformer

Technical Field

This invention relates to a power transformer of the kind having at least one electrical winding comprising electrical conducting means, cooling means for cooling the electrical conducting means to improve its electrically conducting properties, and surrounding electrically insulating means. In particular, but not exclusively, the conducting means has superconducting properties and the invention relates to superconducting power transformers having rated power outputs ranging from several hundred kVA to in excess of 1000 MVA and rated voltages of from 3-4 kV to very high transmission voltages, such as 400 kV to 800 kV. Although the invention primarily relates to core type transformers, the invention may also relate to other types of transformer, such as shell type transformers and coreless, e.g. air core, transformers.

Background of the Invention

Type II superconductors (e.g. niobium titanium, NbTi) can be characterised by their property of changing gradually from a superconducting state to a resistive normal state when subjected to an increasing external magnetic field. Instead of passing directly to the normal state, these materials enter a second phase, called the vortex or mixed state, in which some of the magnetic induction B penetrates the material in the form of flux lines and tiny losses occur when direct current flows. As the applied magnetic field increases, more and more magnetic induction penetrates the material until at some field called H_{c2} the superconductor becomes saturated and goes normal. The physical properties of a type II superconductor can be summarised in the temperature, magnetic field and current density graph shown in Figure 1. All known superconductors of potential interest to the power sector are type II superconductors that operate while in the mixed state.

Thermodynamic equilibrium in a superconductor is reached when the magnetic induction is distributed uniformly - a condition that cannot occur when a current is flowing through the superconductor. When the magnetic induction is moving and current is flowing, a measurable energy loss occurs which is not desirable for power applications. Materials in which the field moves and equilibrium is reached quickly are known as "reversible" or "soft". Materials in which the field does not move (the field is said to be "pinned") are called "irreversible" or "hard" Type II superconductors.

When current flows through a superconductor in the presence of a magnetic field, the Lorentz force F (the product of J, the current density, and B, the magnetic induction) tries to move the flux lines sideways. As the current density and/or magnetic induction increase, the Lorentz force increases until the pinning force is exceeded and the flux lines begin to move, thereby dissipating energy. The point at which the flux lines begin to move is termed the critical current density, J_c, which depends upon the magnetic inductance and temperature as illustrated in Figure 1. Typically T_c is designated as the transition or critical temperature for zero applied magnetic field and zero current density. Likewise, it is customary to designate H_c as the critical magnetic field for zero temperature and zero current density. However J_c conventionally designates the critical current density under actual operating conditions, e.g. 77 K in a field of 1 T.

Conventional "low temperature" Type II superconductors, which operate at temperatures close to absolute zero, have been known for many years. However the useful application of such superconductors has been hindered by the need to use expensive liquid helium cooling to keep the superconductors below 4 K. More recently high-temperature Type II superconductors (hereafter referred to as "HTS") have been developed which have a transition or critical temperature T_c of up to 135 K (or 164 K with

pressure), i.e. well above th boiling point of liquid nitrogen at 77 K. Since the discovery of HTS, the design of superconducting power transformers has become attractive.

Amongst the advantages of superconducting power transformers over conventional oil filled transformers are the reduction in size and weight of, smaller ohmic losses in, the elimination of transformer oil from, and the resultant reduction in the cost of manufacture of superconducting power transformers. A discussion in more detail of known superconducting power transformers and the advantages of such superconducting power transformers over conventional oil-filled transformers is given in the article "Transforming Transformers" by Sam P Mehta, Nicola Aversa and Michael S Walker in "IEEE Spectrum", July 1997.

A typical known superconducting power transformer is disclosed in EP-A-0740315. In this known power transformer, the primary and secondary coils consist of HTS embedded in an epoxy or plastics material. The coils are immersed in a coolant, typically liquid nitrogen, which also serves as a dielectric insulator. If the electric stress caused by the electric field of the superconductor exceeds the dielectric strength of the liquid nitrogen, then discharges will occur, especially if bubbles are formed in the liquid nitrogen. Partial discharges may also occur in the epoxy or plastics material in which the HTS windings are embedded. For instance, when lowering temperatures to cryogenic temperatures for superconductivity, the materials contract. Depending on their composition, the materials will contract at different rates, thus increasing the likelihood of voids forming between the materials, such as between the conductors and epoxy material. To prevent discharges from occurring, the conductors and epoxy material should have identical coefficients of thermal expansion, but this is only possible if the materials involved are the same.

Summary of the Invention

An aim of the present invention is to provide an improved power transformer having cooled windings, e.g. of superconductors such as high-temperature superconductors, provided with electrical insulation which is not prone to corona discharge problems.

According to the present invention a power transformer of the kind referred to is characterised in that the electrically insulating means comprises an inner layer of semiconducting material in electrical contact with said electrical conducting means, an outer layer of semiconducting material at a controlled electrical potential along its length and an intermediate layer of electrically insulating material between the inner and outer layers.

In this specification the term "semiconducting material" means a material which has a considerably lower conductivity than an electric conductor but which does not have such a low conductivity that it is an electrical insulator. Suitably, but not exclusively, a semiconducting material should have a volume resistivity of from 1 to 10^5 ohm·cm, preferably from 10 to 500 ohm·cm and most preferably from 10 to 100 ohm·cm, typically 20 ohm·cm.

The electrical insulation is conveniently of substantially unitary form with the layers either in close mechanical contact or, more preferably, joined together, e.g. bonded by extrusion. The layers are conveniently formed of plastics material having resilient or elastic properties at least at ambient operating temperatures. This allows the cable forming the winding to be flexed and shaped into the desired form of the winding. By using for the layers only materials which can be manufactured with few, if any, defects having similar thermal properties, thermal and el ctric loads within the insulation are reduced. In particular the insulating intermediate layer and the

semic nducting inner and outer layers should have at least substantially the same coefficients of thermal expansion (α) so that defects caused by different thermal expansions when the layers are subjected to heating or cooling will not arise. Ideally the layers will be extruded together around the conducting means.

Conveniently the electrically insulating intermediate layer comprises solid thermoplastics material, such as low or high density polyethylene (LDPE or HDPE)), polypropylene (PP), polybutylene (PB), polymethylpentene PMP), ethylene (ethyl) acrylate copolymer, cross-linked materials, such as cross-linked polyethylene (XLPE), or rubber insulation, such as ethylene propylene rubber (EPR) or silicone rubber. The semiconducting inner and outer layers may comprise similar material to the intermediate layer but with conducting particles, such as particles of carbon black or soot, embedded therein. Generally it has been found that a particular insulating material, such as EPR, has similar mechanical properties when containing no, or some, carbon particles. The intermediate layer may be divided into two or more sub-layers by one or more additional intermediate layers of semiconducting material.

The screens of semiconducting inner and outer layers form substantially equipotential surfaces on the inside and outside of the insulating intermediate layer so that the electric field, in the case of concentric semiconducting and insulating layers, is substantially radial and confined within the intermediate layer. In particular, the semiconducting inner layer is arranged to be in electrical contact with, and to be at the same potential as, the conducting means which it surrounds. The semiconducting outer layer is designed to act as a screen to prevent losses caused by induced voltages. Induced voltages in the outer layer could be reduced by increasing the resistance of the outer layer. The resistance can be increased by reducing the thickness of the outer layer but the thickness cannot be reduced below a c rtain minimum thickness. The resistance can also be increased by selecting a material for the layer

having a higher resistivity. On the other hand, if the resistivity of the semiconducting outer layer is too great, the voltage potential midway between adjacent spaced apart points at a controlled, e.g. earth, potential will become sufficiently high as to risk the occurrence of corona discharge in the insulation with consequent erosion of the insulating and semiconducting layers. The semiconducting outer layer is therefore a compromise between a conductor having low resistance and high induced voltage losses but which is easily connected to a controlled potential, typically earth or ground potential, and an insulator which has high resistance with low induced voltage losses but which needs to be connected to the controlled potential along its length. Thus the resistivity ρ_s of the semiconducting outer layer should be within the range $\rho_{min}<\rho_s<\rho_{max}$, where ρ_{min} is determined by permissible power loss caused by eddy current losses and resistive losses caused by voltages induced by magnetic flux and ρ_{max} is determined by the requirement for no corona or glow discharge.

If the semiconducting outer layer is earthed, or connected to some other controlled potential, at spaced apart intervals along its length, there is no need for an outer metal shield and protective sheath to surround the semiconducting outer layer. The diameter of the cable is thus reduced allowing more turns to be provided for a given size of winding.

In most practical applications, the conducting means has superconducting properties. However, the invention is not intended to be limited to conducting means having superconducting properties and is intended to cover any conducting means whose electrical conducting properties significantly improve at low temperatures, e.g. at temperatures below 200 K. In the preferred case of conducting means having superconducting properties, the conducting means may comprise low temperature semiconductors, but most preferably comprise HTS materials, for example HTS wires or tape helically wound on an inner

tube. A convenient HTS tape comprises silver-sheathed BSCCO-2212 or BSCCO-2223 (where the numerals indicate the number of atoms of each element in the [Bi, Pb]$_2$ Sr$_2$ Ca$_2$ Cu$_3$ O$_x$ molecule) and hereinafter such HTS tapes will be referred to as "BSCCO tape(s)". BSCCO tapes are made by encasing fine filaments of the oxide superconductor in a silver or silver oxide matrix by a powder-in-tube (PIT) draw, roll, sinter and roll process. Alternatively the tapes may be formed by a surface coating process. In either case the oxide is melted and resolidified as a final process step. Other HTS tapes, such as TiBaCaCuO (TBCCO-1223) and YBaCuO (YBCO-123) have been made by various surface coating or surface deposition techniques. Ideally an HTS wire should have a current density beyond $j_c \sim 10^5$ Acm^{-2} at operation temperatures from 65 K, but preferably above 77 K. The filling factor of HTS material in the matrix needs to be high so that the engineering current density $j_e \geq 10^4$ Acm^{-2}. j_c should not drastically decrease with applied field within the Tesla range. The helically wound HTS tape is cooled to below the critical temperature T_c of the HTS by a cooling fluid, preferably liquid nitrogen, passing through the inner support tube.

A cryostat layer may be arranged around the helically wound HTS tape to thermally insulate the cooled HTS tape from the electrically insulating material. Alternatively, however, the cryostat layer may be dispensed with and, instead, the entire windings assembly immersed in a coolant, e.g. a liquid nitrogen bath. In this latter case, the electrically insulating material may be applied directly over the conducting means. Alternatively a space may be provided between the conducting means and the surrounding insulating material, the space either being a void space or a space filled with compressible material, such as a highly compressible foamed material. The space reduces expansion/contraction forces on the insulation system during heating from/cooling to cryogenic temperatures. If the space is filled with compressible material, the latter can

b made semiconducting to ensure electrical contact between the semiconducting inner layer and the conducting means.

Other designs of conducting means are possible, the invention being directed to transformer windings, formed from cooled, preferably superconducting cables of any suitable design having a surrounding electrical insulation of the type described above. For example other types of conducting means having superconducting properties may comprise, in addition to internally cooled HTS, externally cooled HTS or externally and internally cooled HTS. In the latter type of HTS cable, two concentric HTS conductors separated by cryogenic insulation and cooled by liquid nitrogen are used to transmit electricity. The outer conductor acts as the return path and both HTS conductors may be formed of one or many layers of HTS tape for carrying the required current. The inner conductor may comprise HTS tape wound on a tubular support through which liquid nitrogen is passed. The outer conductor is cooled externally by liquid nitrogen and the whole assembly may be surrounded by a thermally insulating cryostat.

It is desirable to have a low external magnetic field in order to allow for higher current densities in the superconducting state. In a particularly preferred design, this is achieved by mixing low and high voltage windings of the transformer. In this way, the magnetic fields at least partially cancel each other, thus reducing the leakage inductance and allowing for higher critical current densities. In a conventional superconducting transformer this is very difficult to achieve since the windings have to be dielectrically insulated from each other requiring the windings to be spaced from each other. In the present invention, the electric field outside the windings is negligible enabling high and low voltage windings to be intermixed resulting in a more compact transformer design.

Brief Description of the Drawings

Embodiments of the invention will now be described, by way of example only, with particular reference to the accompanying drawings, in which:

Figure 1 is a graph showing the variation in temperature, magnetic field and current density of a Type II superconductor;

Figure 2 is a schematic view of a magnetic core and windings of a power transformer according to the invention;

Figure 3 is a sectional view taken on the line A - A of Figure 2;

Figure 4 is schematic sectional view, on an enlarged scale, through part of a superconducting cable from which a winding of the transformer is wound; and

Figures 5A and 5B are schematic illustrations of portions of high and low voltage windings intermixed together and wound about a transformer core limb.

Figures 2 and 3 show a three-phase superconducting power transformer 1 comprising a laminated magnetic core 2 having limbs 3, 4 and 5 for the three different phases and connecting upper and lower yokes 6 and 7. The limbs 3, 4 and 5 have windings 8, 9 and 10, respectively, wound on them. Each winding 8, 9, 10 comprises three concentric winding turns separated from each other by electrical insulation 11. With regard to the winding 8, the innermost windings 8a and 8b represent the primary windings or high voltage windings and the other winding 8c represents the secondary or low voltage winding.

Each winding is formed from superconducting cable 12 shown schematically in Figure 4. The superconducting cable

12 comprises an inner copper tubular supp rt 13 on which is helically wound elongate HTS material, for example BSCCO tape or the like, to form a superconducting layer 14 around the tubular support 13. A cryostat 15, arranged outside the superconducting layer, comprises two spaced apart flexible corrugated metal tubes 16 and 17. The space between the tubes 16 and 17 is maintained under vacuum and contains thermal superinsulation 18. Liquid nitrogen, or other cooling fluid, is passed along the tubular support 13 to cool the surrounding superconducting layer 14 to below its critical superconducting temperature T_c. The tubular support 13, superconducting layer 14 and cryostat 15 together constitute superconducting means of the cable 12.

Electrical insulation is arranged outside the superconducting means. The electrical insulation is of unified form comprising an inner semiconducting layer 20 in electrical contact with the superconducting layer 14, an outer semiconducting layer 21 and, sandwiched between these semiconducting layers, an insulating layer 22. The layers 20-22 preferably comprise thermoplastics materials in close mechanical contact or preferably solidly connected to each other at their interfaces. Conveniently these thermoplastics materials have similar coefficients of thermal expansion and are resilient or elastic at least at room temperature. Preferably the layers 20-22 are extruded together around the inner superconducting means to provide a monolithic structure so as to minimise the risk of cavities and pores within the electrical insulation. The presence of such pores and cavities in the insulation is undesirable since it gives rise to corona discharge in the electrical insulation at high electric field strengths. If the semiconducting layer 20 is in contact with the tube 17, the contacting surfaces should be smooth to cater for thermal movement between the surfaces when changes occur in the thermal gradient between the inside and outside of the cable 12.

By way of example only, th s lid insulating layer 22 may comprise cross-linked polyethylene (XLPE). Alternatively, however, the solid insulating layer may comprise other cross-linked materials, low density polyethylene (LDPE), high density polyethylene (HDPE), polypropylene (PP), or rubber insulation, such as ethylene propylene rubber (EPR), ethylene-propylene-diene monomer (EPDM) or silicone rubber. The semiconducting material of the inner and outer layers 20 and 21 may comprise, for example, a base polymer of the same material as the solid insulating layer 22 and highly electrically conductive particles, e.g. particles of carbon black or metallic particles, embedded in the base polymer. The volume resistivity, e.g. about 20 ohm·cm, of these semiconducting layers may be adjusted as required by varying the type and proportion of carbon black added to the base polymer. The following gives examples of how the resistivity can be varied using different types and quantities of carbon black.

Base Polymer	Carbon Black Type	Carbon Black Quantity (%)	Volume Resistivity Ω·cm
Ethylene vinyl acetate copolymer/ nitrite rubber	EC carbon black	~15	350-400
-"-	P-carbon black	~37	70-10
-"-	Extra conducting carbon black, type I	~35	40-50
-"-	Extra conducting black, type II	~33	30-60
Butyl grafted polyethylene	-"-	~25	7-10
Ethylene butyl acrylate copolymer	Acetylene carbon black	~35	40-50
-"-	P carbon black	~38	5-10
Ethylene propene rubber	Extra conducting carbon black	~35	200-400

The outer semiconducting layer 21 is connected at spaced apart regions along its length to a controlled potential. In most practical applications this controlled

potential will be earth or ground potential, the specific spacing apart of adjacent earthing points being dependent on the resistivity of the layer 21.

The semiconducting layer 21 acts as a static shield and as an earthed outer layer which ensures that the electric field of the superconducting cable is retained within the solid insulation between the semiconducting layers 20 and 21. Losses caused by induced voltages in the layer 21 are reduced by increasing the resistance of the layer 21. However, since the layer 21 must be at least of a certain minimum thickness, e.g. no less than 0.8 mm, the resistance can only be increased by selecting the material of the layer to have a relatively high resistivity. The resistivity cannot be increased too much, however, else the voltage of the layer 21 mid-way between two adjacent earthing points will be too high with the associated risk of corona discharges occurring.

The thickness of the electrical insulation need not be uniform along the length of the winding. The thickness needs to be greater for high voltages and need not be as thick for lower voltages. Accordingly the thickness of the electrical insulation may be stepped along its length, the thicker insulation being at the high voltage end(s) of the winding. In practice cables with different insulation thicknesses are joined together to form a particular winding. If, for instance, a winding is formed about a core type transformer, a cable with one thickness of electrical insulation may be wound around a core limb and then be joined outside the core structure to another cable with a different thickness of electrical insulation. This other cable is then wound around the core limb. Further cables may be joined along the length of the winding at joints positioned away from the core structure resulting in a winding having different thicknesses of insulation along its length.

The windings 8a, 8b and 8c need not be physically separate from each other and, indeed, a preferred arrangement is to intermix the windings so as to reduce the leakage inductance. This is rendered possible since the electric field outside the windings is negligible. By reducing the leakage inductance, a higher critical current density can be catered for. In addition, intermixing of the windings allows the transformer to be of more compact design, especially where the windings are of "stepped" form, described above, with electrical insulations of different thicknesses.

Examples of mixed windings are shown schematically in Figures 5A and 5B. Figure 5A shows a transformer with a transformation ratio of 1:2 with low voltage winding layers designated 26 and high voltage winding layers designated 28. Laminated magnetic material 27 and spacers 29 for providing air gaps are located between various winding layers and turns to improve transformer efficiency. Figure 5B shows an arrangement where turns and layers of low voltage windings 30 and high voltage winding 32 are symmetrically and evenly intermixed in a regular manner.

Although the present invention is primarily directed to power transformers having windings in which the conducting means have superconducting properties and are cooled to such superconducting temperatures in use, the invention is also intended to embrace conducting means which have improved electrical conductivity at a low operating temperature, up to, but preferably no more than, 200 K, but which may not possess superconducting properties at least at the intended low operating temperature. At these higher cryogenic temperatures, liquid carbon dioxide can be used for cooling the conductor means.

The electrically insulating means of a power transformer according to the invention is intended to be able to handle very high voltages and the consequent electric and thermal loads which may arise at these

voltages. By way of example, power transformers according to the invention may have rated powers from a few hundred kVA up to more than 1000 MVA and with rated voltages ranging from 3-4 kV up to very high transmission voltages of 400-800 kV. At high operating voltages, partial discharges, or PD, constitute a serious problem for known insulation systems. If cavities or pores are present in the insulation, internal corona discharge may arise whereby the insulating material is gradually degraded eventually leading to breakdown of the insulation. The electric load on the electrical winding insulation of a power transformer according to the present invention is reduced by ensuring that the inner layer of the insulation is at substantially the same electric potential as the inner conducting means and the outer layer of the insulation is at a controlled, e.g. earth, potential. Thus the electric field in the intermediate layer of insulating material between the inner and outer layers is distributed substantially uniformly over the thickness of the intermediate layer. Furthermore, by having materials with similar thermal properties and with few defects in the layers of the insulating material, the possibility of PD is reduced at a given operating voltages. The power transformer can thus be designed to withstand very high operating voltages, typically up to 800 kV or higher.

Although it is preferred that the electrically insulating means should be extruded in position, it is possible to build up an electrical insulation system from tightly wound, overlapping layers of film or sheet-like material. Both the semiconducting layers and the electrically insulating layer can be formed in this manner. An insulation system can be made of an all-synthetic film with inner and outer semiconducting layers or portions made of polymeric thin film of, for example, PP, PET, LDPE or HDPE with embedded conducting particles, such as carbon black or metallic particles and with an insulating layer or portion between the semiconducting layers or portions.

For the lapped concept a sufficiently thin film will have butt gaps smaller than the so-called Paschen minima, thus rendering liquid impregnation unnecessary. A dry, wound multilayer thin film insulation has also good thermal properties and can be combined with a superconducting pipe as an electric conductor and have coolant, such as liquid nitrogen, pumped through the pipe.

Another example of an electrical insulation system is similar to a conventional cellulose based cable, where a thin cellulose based or synthetic paper or non-woven material is lap wound around a conductor. In this case the semiconducting layers, on either side of an insulating layer, can be made of cellulose paper or non-woven material made from fibres of insulating material and with conducting particles embedded. The insulating layer can be made from the same base material or another material can be used.

Another example of an insulation system is obtained by combining film and fibrous insulating material, either as a laminate or as co-lapped. An example of this insulation system is the commercially available so-called paper polypropylene laminate, PPLP, but several other combinations of film and fibrous parts are possible. In these systems various impregnations such as mineral oil or liquid nitrogen can be used.

CLAIMS

1. A power transformer (1) having at least one electrical winding comprising electrical conducting means (13-15), cooling means for cooling the electrical conducting means to improve its electrical conductivity, and surrounding electrically insulating means (20-22), characterised in that the electrically insulating means comprises an inner layer (20) of semiconducting material in electrical contact with said electrical conducting means, an outer layer (21) of semiconducting material at a controlled electrical potential along its length and an intermediate layer (22) of electrically insulating material between the said inner and outer layers (20,21).

2. A power transformer according to claim 1, characterised in that the semiconducting outer layer (21) has a resistivity of from 1 to 10^5 ohm·cm.

3. A power transformer according to claim 1, characterised in that the said outer layer (21) has a resistivity of from 10 to 500 ohm·cm, preferably from 10 to 100 ohm·cm.

4. A power transformer according to any one of claims 1 to 3, characterised in that the resistance per axial unit length of the semiconducting outer layer (21) is from 5 to 50,000 ohm.m^{-1}.

5. A power transformer according to any one of claims 1 to 3, characterised in that the resistance per axial unit of length of the semiconducting outer layer (21) is from 500 to 25,000 ohm.m^{-1}, preferably from 2,500 to 5,000 ohm.m^{-1}.

6. A power transformer according to any one of the preceding claims, characterised in that the semiconducting outer layer (21) is contacted by c nductor means at said controlled electrical potential at spaced apart regions

along its length, adjacent contact regions being sufficiently close together that the v ltages of mid-points between adjacent contact regions are insufficient for corona discharges to occur within the electrically insulating means.

7. A power transformer according to any one of the preceding claims, characterised in that said controlled electrical potential is at or close to ground potential.

8. A power transformer according to any one of the preceding claims, characterised in that the said intermediate layer (22) is in close mechanical contact with each of said inner and outer layers (20 and 21).

9. A power transformer according to any one of claims 1 to 7, characterised in that the said intermediate layer (22) is joined to each of said inner and outer layers (20 and 21).

10. A power transformer according to claim 9, characterised in that the strength of the adhesion between the said intermediate layer (22) and the semiconducting outer layer (21) is of the same order of magnitude as the intrinsic strength of the material of the intermediate layer.

11. A power transformer according to claim 9 or 10, characterised in that the said layers (20-22) are joined together by extrusion.

12. A power transformer according to claim 11, characterised in that the inner and outer layers (20,21) of semiconducting material and the insulating intermediate layer (22) are applied together over the conducting means through a multi layer extrusion die.

13. A power transformer according to any one of the preceding claims, characterised in that said inner layer

(20) comprises a first plastics material having first electrically conductive particles dispersed therein, said outer layer (21) comprises a second plastics material having second electrically conductive particles dispersed therein, and said intermediate layer (22) comprises a third plastics material.

14. A power transformer according to claim 13, characterised in that each of said first, second and third plastics materials comprises an ethylene butyl acrylate copolymer rubber, an ethylene-propylene-diene monomer rubber (EPDM), an ethylene-propylene copolymer rubber (EPR), LDPE, HDPE, PP, XLPE, EPR or silicone rubber.

15. A power transformer according to claim 13 or 14, characterised in that said first, second and third plastics materials have at least substantially the same coefficients of thermal expansion.

16. A power transformer according to claim 13, 14 or 15, characterised in that said first, second and third plastics materials are the same material.

17. A power transformer according to any one of the preceding claims, characterised in that the said conducting means (13-15) has superconducting properties and in that said cooling means is arranged to cool the conducting means below the critical temperature of the latter.

18. A power transformer according to claim 17, characterised in that the conducting means comprises HTS material.

19. A power transformer according to claim 18, characterised in that the HTS material comprises helically wound HTS tapes or conductors.

20. A power transformer according to claim 18, characterised in that the HTS material comprises HTS tape

helically wound on a support tube and in that cooling fluid, e.g. liquid nitrogen, is passed through the support tube to cool the HTS tape below the critical temperature of the HTS material.

21. A power transformer according to any one of claims 17 to 20, characterised in that the conducting means includes a thermally insulating outer layer.

22. A power transformer according to any one of claims 1 to 16, characterised in that, in use of the transformer, the said cooling means cools the conducting means to below 200 K.

23. A power transformer according to any one of the preceding claims, characterised in that the semiconducting inner layer has a resistivity of from 1 to 10^5 ohm-cm, typically from 10 to 500 ohm-cm and preferably from 50 to 100 ohm-cm.

24. A power transformer according to any of the preceding claims in which low and high voltage windings are mixed together to reduce the leakage inductance.

25. A power transformer according to any one of the preceding claims, characterised in that the said electrically insulating means is designed for high voltage, suitably in excess of 10 kV, in particular in excess of 36 kV, and preferably more than 72.5 kV up to very high transmission voltages, such as 400 kV to 800 kV or higher.

26. A power transformer according to any one of the preceding claims, characterised in that the said electrically insulating means is designed for a power range in excess of 0.5 MVA, preferably in excess of 30 MVA and up to 1000 MVA.

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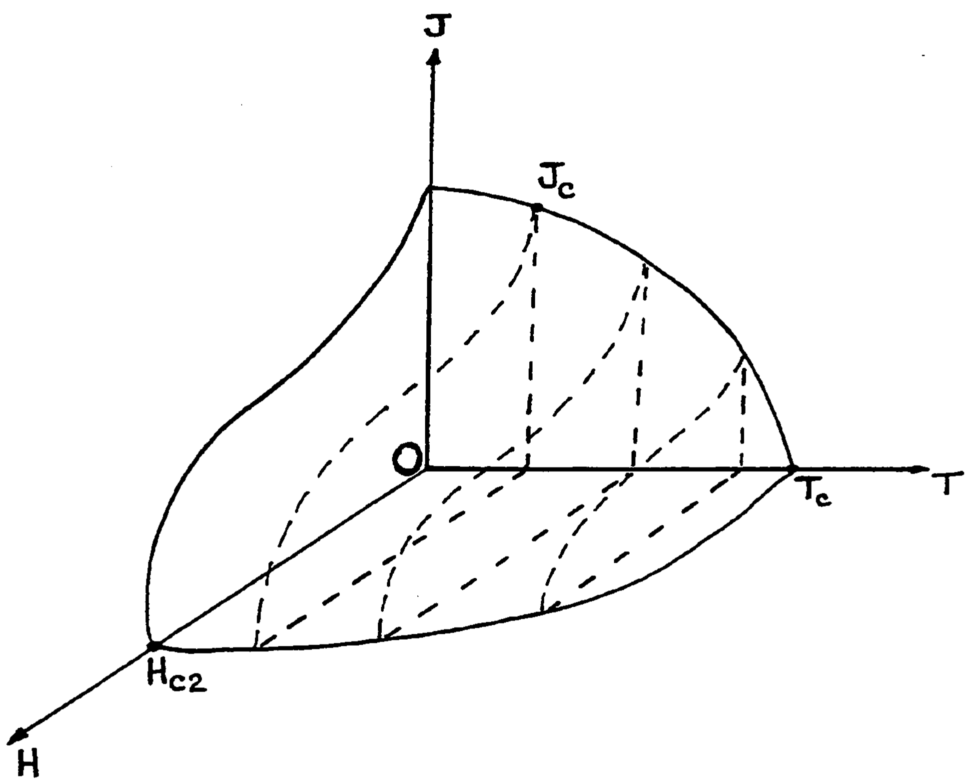
FIG. 1.



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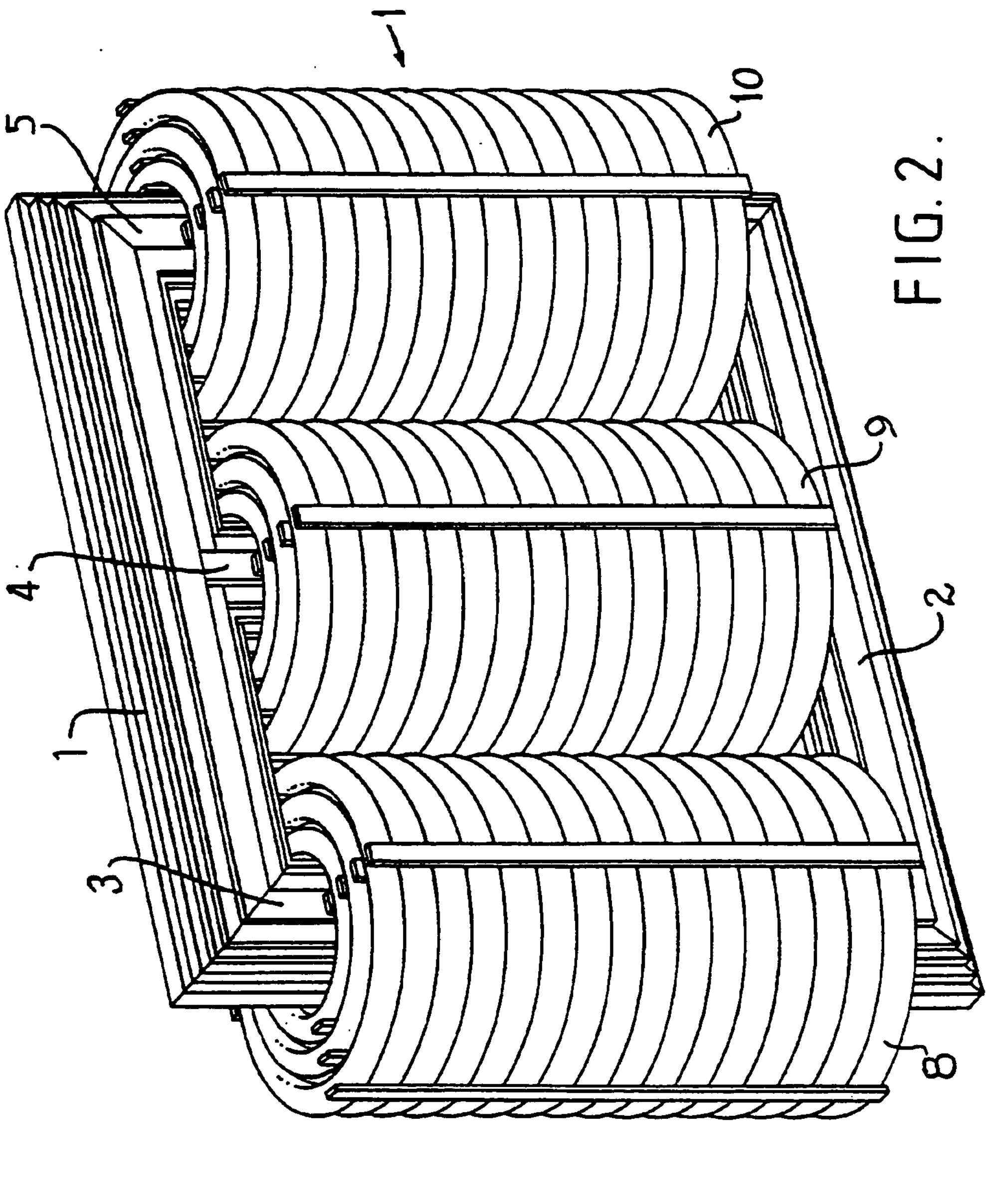

FIG. 2.

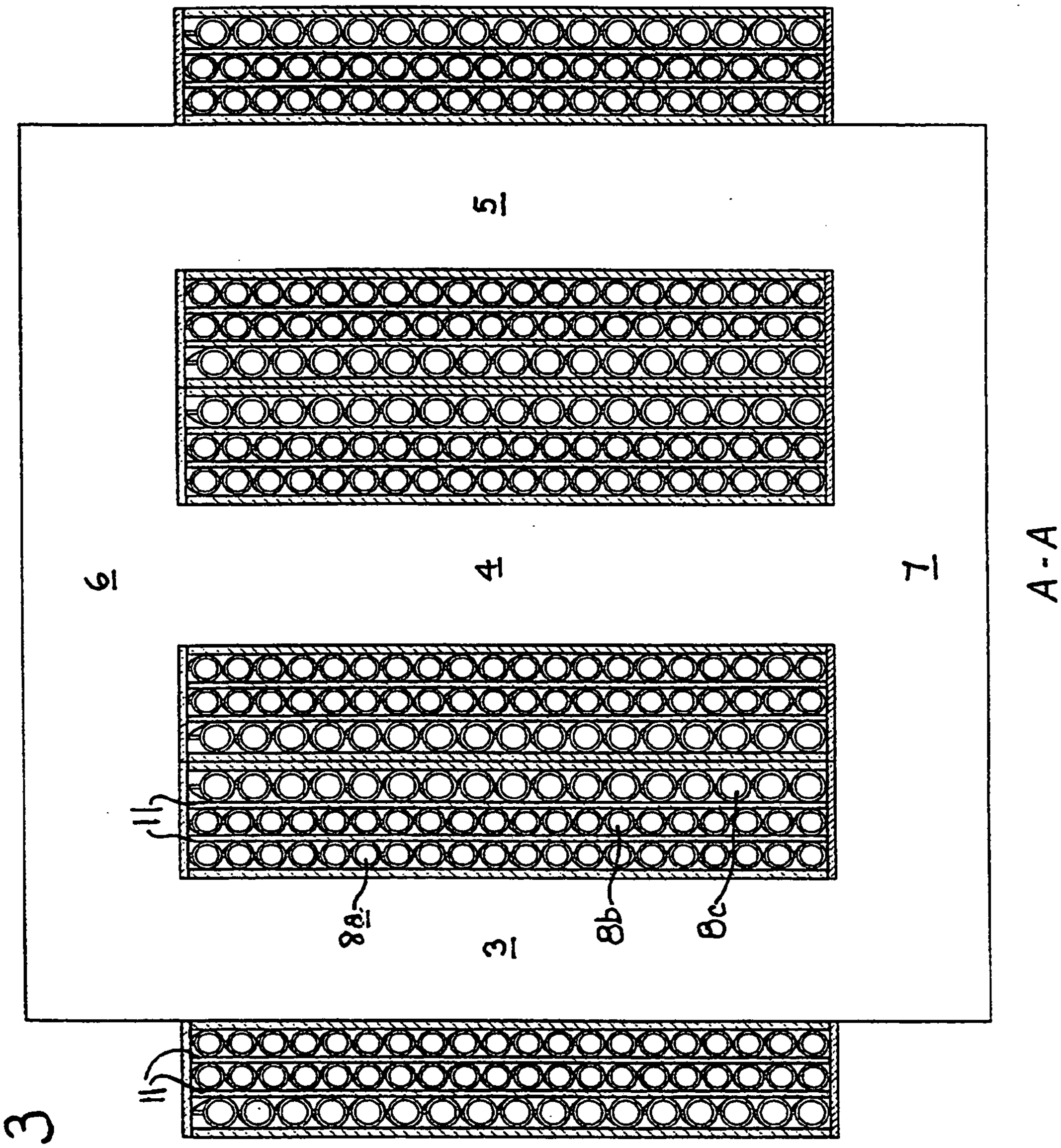

FIG. 3

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FIG.4.

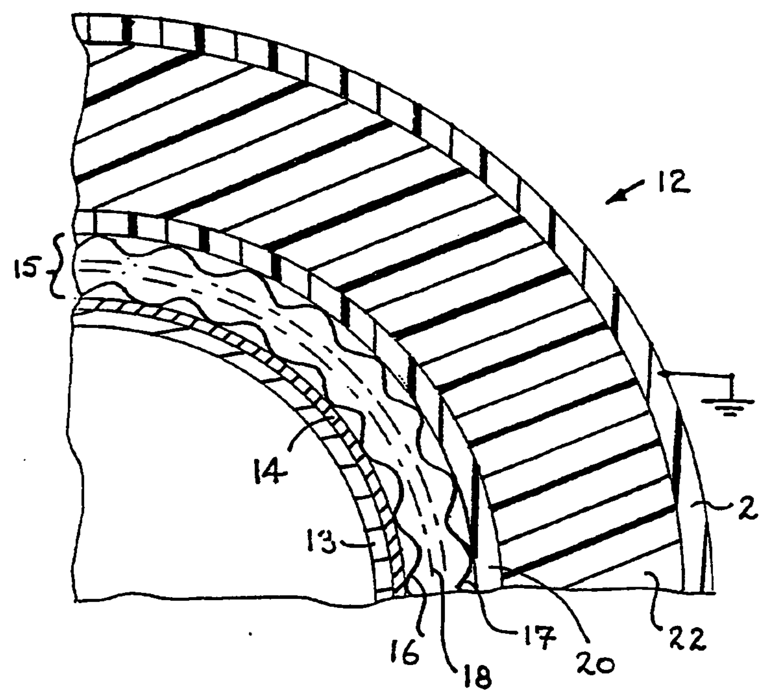
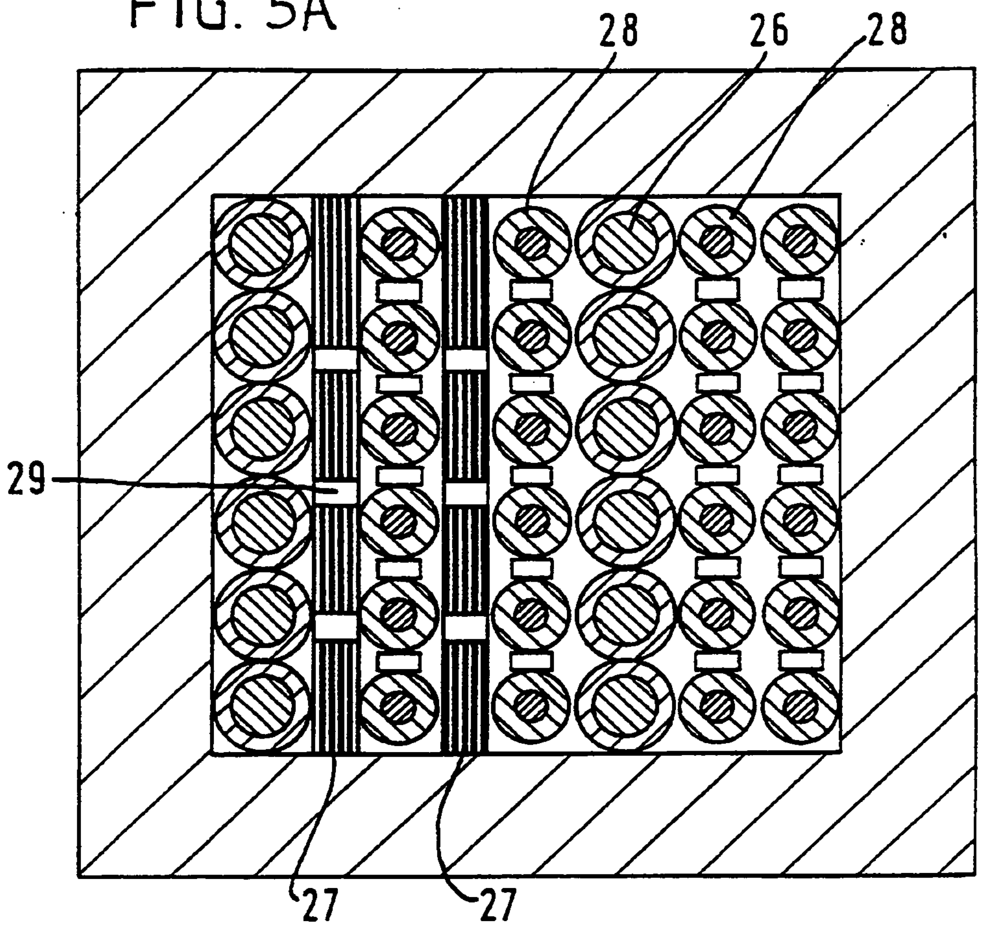


FIG. 5A



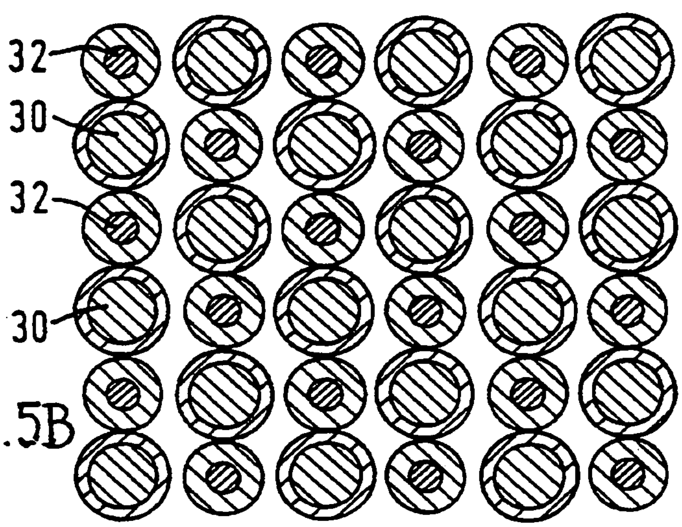


FIG.5B

INTERNATIONAL SEARCH REPORT

Inter. ...onal Application No
PCT/EP 98/07736

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 H01F36/00 H02K3/40 H01F6/04

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 H01F H02K

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	DE 40 22 476 A (THYSSEN INDUSTRIE) 16 January 1992 see column 1, line 31 - line 36 see column 3, line 11 - column 4, line 53; figures 1-3	1,6-9, 11,13, 14,25
A	GB 2 140 195 A (ELECTRIC POWER RESEARCH INSTITUTE) 21 November 1984 see page 1, line 108 - page 2, line 107; figures 1-4	1,8,9, 11,13, 14,17, 21,22
A	EP 0 740 315 A (ABB) 30 October 1996 see column 2, line 38 - column 7, line 15; figures 1-7	1,17,18

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

° Special categories of cited documents :

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"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
26 April 1999	03/05/1999

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Demolder, J

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INTERNATIONAL SEARCH REPORT

Information on patent family members

Inten. ..onal Application No
PCT/EP 98/07736

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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		JP 8298209 A	12-11-1996
		US 5689223 A	18-11-1997